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Dynamic Systems, Process and Development

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Keywords

Development · Complex dynamic systems · Process · Substance · Causality · Structure · Methodology · Emergence · Timescales

Abstract

In this article, I answer the questions from Witherington and Boom's introduction to this special issue in the form of an imaginary interview, led by David Boom, equally imaginary editor of *The Processual Inquirer*, an obscure but interesting journal that appears in imaginary physical print only, and which, as a consequence, has so far left no traces on the Internet....

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Dynamics of Development and Causality

David Boom (D.B.): What does it mean for you to study the dynamics of development? And how is causality conceptualized in your dynamics orientation on understanding of process in development?

Paul van Geert (P.G.): Your question refers to four basic notions, *dynamics*, *development*, *causality* and *process*, which are very hard to define without running into circles or tautologies. Their meaning is basically a question of how they are used, in this particular case by the community of developmental researchers, which is in itself a very complex issue. In such cases, to open the discussion I always find it a good heuristic strategy – and no more than that – to go back to the origins of the concepts, their etymology, to see if it can shed some new light on our understanding of what those concepts mean.

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Let us for the time being confine ourselves to dynamics and development. Dynamic comes from the Greek *dynamikos* “powerful,” from *dynamis* “power, might, strength.” Gottfried Wilhelm Leibniz introduced the term in a philosophical essay in 1695, where he says that every “bodily thing” has a basic property, namely its force, which is its ability to do something, to act upon other things, or to withstand, to a certain degree, to be changed by other things. In that sense, dynamics implies change as a consequence of the forces or powers inherent in things that change (later in history, the “thing” aspect would disappear entirely). Leibniz also invented differential calculus (and Newton invented it almost simultaneously, independent of him), which is the indispensable mathematical tool for dealing with change, which is a fundamental and basic feature of all physical, biological or psychological phenomena. For what it’s worth, it is interesting to observe that in developmental psychology, which is the quintessential science of human psychological change, differential equations are virtually inexistent. For me, this general notion of dynamics is inextricably connected with the theory of dynamic systems and complex dynamic systems that should form the backbone of any science of change in general and developmental psychology in particular.

Dynamic Systems

D.B.: I guess that this means that you want to explain what dynamic systems and complex dynamic systems mean before you go on with the next part of my question?

P.G.: Let me begin with a simple definition of dynamic systems.

A dynamic system is a system whose current state generates its successive state by a rule or principle of change (the so-called evolution rule) and thus produces a trajectory in a state space. System can be defined as any whole of connected elements, that is, the things that form a “whole” through their connections, connections that are supposed to have a certain durability. The state of the system can be any “slice” an observer wishes to make through the ongoing process; it is the current value or values of the property or properties that are used to characterize the system. And the state space is nothing more than the space formed by such properties. The evolution rule or principle of change is anything that generates the next state out of the current one. For each dimension in the state space (that is to say, for each variable or component) you have to specify a rule of change, and these rules of change are coupled. What happens in one dimension or variable has an effect on what happens in another. It is the coupling between these dimensions or variables that explains why the whole thing is a system (Table 1).

An important form of change is zero change, i.e. stability, where the dynamics actively re-creates its preceding state into the current state. Stability and endurance are not the basic or default states of the world, as they would be in a typical substance-oriented ontology. In fact, they are the highly specific products of ongoing interacting processes.

Sometimes the evolution rule can be simplified to a mathematical expression, for instance in the form of a differential or difference equation (e.g. Van Geert, 1991, 1994), but sometimes the dynamics are simply too complex to be represented by such

Table 1. A dynamic system

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- Is a system whose current state generates its successive state by a rule or principle of change and thus produces a trajectory in a state space (Weisstein, 2018)
 - System: any whole of connected elements (forming a “whole” through their connections)
 - State: current value(s) of the property(s) that one uses to describe the system
 - Rule/principle of change: anything that generates the next state out of the current one; the system’s “evolution rule,” which is the “mechanism” of its change
-

Examples of formalizations

- The next state is a function of the current state

$$x_{t+1} = f(x_t) \text{ or } \frac{\Delta x}{\Delta t} = f(x)$$

- Successive application of this principle defines a flow, sequence or process
 $x_{t+1} = f(x_t) \rightarrow x_{t+2} = f(x_{t+1}) \rightarrow x_{t+3} = f(x_{t+2}) \rightarrow \dots$
 - A state space consisting of more than one dimension requires coupling between the dimensions in the form of coupled functions, describing interactions between 2 or more variables or components of the system
 $[x_{t+1} = f(x_t, y_t); y_{t+1} = f'(y_t, x_t)] \rightarrow [x_{t+2} = f(x_{t+1}, y_{t+1}); y_{t+2} = f'(y_{t+1}, x_{t+1})] \rightarrow \text{etc.}$
-

Note: for simplicity, I use the difference equation, based on a step of duration 1, which could in fact be as long or short as one wishes. The differential format could be something like $\frac{\Delta x}{\Delta t} = f(x)$ and it is supposed to represent a continuous flow.

a mathematical function (which requires a conceptual model of why a particular property is changing over time). In that case, we have the possibility to represent it in the form of possible trajectories of a ball rolling over a landscape of hills and valleys, in principle moving away from the hills and resting at the bottom of valleys (epigenetic landscapes). This landscape represents the change in a mathematical function describing a potential field, and by doing so, it can describe typical properties of the dynamics, for instance discontinuities and hysteresis (for an early application to human development, see Van der Maas & Molenaar, 1992, and Newell, Liu & Mayer-Kress, 2003).

This elementary scheme of a coupled system, where one state generates the next, forms the starting point for interesting conceptual extensions, such as feedback, time delays, goal states, long-term histories, stochastic influences, interacting systems, anticipation and so forth.

But every specification of a particular dynamic system is at the same time the specification of a particular interactor with that system, that is, an observer/describer/intervenor, from whose interactions the specification of the system is generated. Potentially, every “real system” has an intractable complexity (a “real system” is basically a system described by all the interactions that it can possibly entertain, on all possible levels of its physical and temporal organization). For that reason, our understanding of the dynamics of the system usually occurs through the selection of a couple of properties generated by our interactions with that system in the form of observations, measurements or joint activities. By doing so, we can take a few properties out of the system, but we can never take the system out of the properties. That is to

say, our choice of the descriptive state space must be so that changes over these dimensions conserve or represent *characteristic properties of the system as a whole*. Examples of such characteristic properties are temporal patterns of variability, stability, gradual change and discontinuities, irreversibility and reversibility, progress and regress, recurrence and so forth. All this occurs on a variety of coupled coexisting timescales characteristic of the system in question. For instance, we see processes on the timescale of real activities such as in children's playing, making a math assignment in school or having a discussion with a friend, on the timescale of the recurrence of such activities over weeks or months, and on the timescale of long-term changes – variances and invariances – over years or decades that we typically associate with development as a life span process.

Every variable (dimension of the state space, component, ...) we use to describe a system corresponds with some sort of order, structure and recurrence in the processes that characterize the system (e.g., a child's vocabulary, an adolescent's self-esteem-related acts or the spoon-feeding patterns in a parent-infant dyad). Without such order and recurrence, our scientific interactions with and understanding of the system would be totally ephemeral. If we zoom in on a particular variable, we will see that it "explodes" in a multitude of underlying variables. But the recurrent way such variables are connected in typical processes (e.g., using and speaking a particular word, cognitive levels in problem solving) are sufficient for justifying our treatment of them as wholes or structures with a certain autonomy, endurance and recurrence that guarantees their usability as units or foci of analysis.

Instead of conceptualizing these variables as dimensions of a space (the typical geometric approach of classical dynamic systems), they can just as well be conceptualized as nodes in a network, with every node characterized by its changing properties over time, the change of which is caused by its inherent dynamics and by its connections or coupling with other nodes. In addition, the state space may be composed by nominal or ordinal variables (e.g., various forms of emotional reactions during a social interaction). Any pair of such variables forms a grid, like a chessboard, and the dynamics of the system may be described in the form of a series of moves across the grid. The application of such grids, so-called state space grids, is becoming an increasingly popular technique for describing the dynamics of various sorts of developmental changes (e.g., Hollenstein, 2013).

Development: A View from Its Etymology

D.B.: How does this combine with the notion of development?

P.G.: *Development* literally means *to unwrap* (www.etymonline.com/word/develop). The Dutch and German words for development, *ontwikkeling* and *Entwicklung*, respectively, literally translate as *un-wrapping*. That is to say, in its original meaning, development refers to something that is given from the origin onwards, and that waits for its being unwrapped such that it can become manifest. Under this interpretation, development bears a highly nativist sort of connotation, but the etymology is ambiguous, in this regard. First, the wrapping might refer to the object itself, in which case the word means that something is being unfolded, like a leaf folded up in a bud that unfolds itself in spring. Second, the thing present before it unwraps, i.e. develops, could be interpreted as a potential, *potential* meaning power, might, force,

capability, possibility and so forth. And this very likely interpretation brings us back to our first basic concept, namely dynamics, which was defined as a force or power that entails a capability or possibility, that is, a potential. When I combine these analyses of the meaning of dynamics and of development, it seems to me that a meta-theory such as dynamic systems or complex dynamic systems theory, offers a perfect technical, consistent and versatile framework for conceptualizing and studying the dynamics of development, as defined in its semantic roots.

Causality and Complex Dynamic Systems

D.B.: What about causality? How does your dynamics orientation differ from traditional, “cause-effect” or “intervening variable” approaches to the study of mechanisms and processes in psychology? How is causality conceptualized in your dynamics orientation?

The Standard Scheme

P.G.: The Latin *causa* means “a cause; a reason; interest; judicial process, lawsuit, ...” In Germanic languages, such as Dutch and German, the word for cause is *oorzaak* and *Ursache*, respectively, which means “the original or basic ground of something.” In Aristotelian philosophy, which has been very influential in the development of Western science, the word “cause” means “explanation”: a cause is a reason that one invokes if one answers a why-question. Aristotle made the distinction between material, formal, efficient and final causes. The modern, standard conception of causality has reduced this scheme to a very narrow definition of efficient causes only, but this is unfortunate as the notions of cause and explanation (answering a why-question) are so closely related to one another.

Causality is a subtle and complex notion, but the way we habitually talk about causes in the developmental sciences – the praxis of causal statements – enacts a highly limited and specific view on what causality is or represents. In fact, it is a strongly pragmatically inspired use of cause and causality, inspired by our wish to *do* something to change the course of things.

In the standard praxis, we start with some idea of the way things occur “on average” or “normally,” the-world-as-usual, which we basically see as a static thing (there is no change). Then we intervene, which literally means that we “come in between,” that we do something to interrupt the normal course by an external event. We observe that, contingent on this doing, the normal course is deflected, that is, changes its customary route in the direction we expected. Without this intervening, things would have stayed the same (the argument of counterfactuality). In this standard view, we are combining the notion of manipulability – that we can do things to act on the world – with an antecedent (cause)-consequent (effect) scheme, where one thing is in rest, until it is “hit” in some way by another thing, after which the thing in rest moves to another place, to stay there in a resting position until it is hit yet again (it’s basically a sort of billiard ball scheme). In addition, we assume that the cause can be shielded off from other events, so that it can be treated as an independent entity.

D.B.: But doesn't this scheme more or less exhaust the possible ways of scientifically conceptualizing causality? Alternatives such as vital forces or teleological causality have been shown to be incompatible with what we know about forces and causes in nature.

P.G.: The first possibility is that this elementary antecedent-consequent two-event scheme is indeed *the* basic scheme of causality, with all other expressions of causality reducible to ever more complicated combinations of this basic building block (for critical reviews, see Anjum & Mumford, 2018, in biology, and Witherington & Heying, 2015, in developmental psychology). This is what we find in the so-called manipulability or intervention-based theories of causality. A typical technical operationalization of this approach, underscoring causal analysis by means of structural equation modeling, is the theory of directed acyclical graphs by Judea Pearl (e.g., Morgan & Winship, 2012; Pearl & McKenzie, 2018) or the philosophical theory of James Woodward (2005). It is closely related to the so-called counterfactual theories of causality (something is the cause of an effect if that effect wouldn't have happened if the cause didn't happen). We find it back in the standard effectiveness criterion of intervention research.

Dynamic Systems and Process Causality

D.B.: I guess this first option covers the traditional "cause-effect" or "intervening variable" approaches. What is your second option, and how does it relate to dynamic systems?

P.G.: The second option is that this two-event antecedent-consequent causal scheme is a special case subsumed under a more general encompassing scheme of *interactions of forces* that complies with what we know about how nature works.

We can actually begin with dynamic systems as defined earlier, namely as "a system whose current state generates its successive state by a rule or principle of change." That is to say, the current state is the cause of the next state, which is the cause of the state next to it and so forth, all along the process that this sequence of states is representing (states can be discrete steps, or points on a continuum). This scheme defines what is called *process causality* (for introductions, see Rescher, 1996, 2000, Bickhard, 2011, and Seibt, 2018; for developmental psychology in particular, see Overton, 2015, and Witherington, Overton, Lickliter, Marshall & Narvaez, 2018). The so-called evolution rule that defines a particular dynamic system is the expression of the process causality that governs the system (on the notion of process causality, see Salmon, 1994, and Dowe, 2007, 2009).

Classical "intervention" causality can be viewed as a specific case of process causality. Suppose you have a process – a teacher teaching and a student learning, a child developing – that unfolds as a consequence of its inherent process dynamics, i.e. its inherent process causality, which is a function of the way all components contributing to the process are coupled or are interacting (e.g., Vallacher, van Geert, & Nowak, 2015). An intervention can in principle start at any arbitrary moment in this process, but it will usually begin at the point where it is triggered by properties of the ongoing process itself (parents will start spoon feeding at the moment they think their baby is ready for it, which means that the baby triggers the intervention). At this point, these processes will begin to interact over time (the process at issue and the process of intervention).

Properties of the intervention process are assimilated into the system properties at that particular moment in time (the intervention is assimilated in the state space defining the system). The next state of the system is a consequence of the preceding state, which includes the assimilated intervention event (which is not yet the full intervention but just its starting point, whatever that may be). If the intervention goes on, the next state in the process will determine how the intervention is further assimilated into the system, how it intertwines with the system's own dynamics (which might change over the course of time). This interaction will co-determine the next state in the interacting system, and so on until this pattern of coordinations between the processes stops, for instance when this pattern becomes recurrent, i.e. stable, for instance according to normative standards of the participants.

D.B.: Is process causality the only contribution of dynamic systems to our conceptualization of causality in general and in development in particular?

Causality and Complex Dynamic Systems

P.G.: No, it is not. But to understand the full contribution of dynamic systems to our understanding of causality, you need the theory of *complex* dynamic systems. Complexity is often confused with complicatedness. The origin of the word *complex* is “being woven together,” “being intertwined,” whereas *complicated* stems from “being folded together.” Something that is folded must be understood by unfolding it so that its constituent folds become manifest. But something that is woven or intertwined must be understood by observing how it is intertwined. If you take it apart, you lose its essential property of an intertwined whole. To simplify things, you could say that you can understand complicated things by isolating their components, leaving open, more or less, the possible ways in which such components might interact. And you can understand complex things by focusing on the way their components interact, leaving open which components exactly are involved in the interaction (as an exact determination of the latter might be an almost intractable problem if the system is a complex dynamic system).

But what is more important, I think, is that complex systems – interacting intertwined wholes – have a number of very important properties that are directly relevant to the issues of causality as well as development. The first property is that any lasting form of interaction between many components is an expression of *self-organization*. For simplicity, you could think of putting any number of components together – persons, emotions, skills, cells, material objects, etc. – and see what happens when they interact, if they interact at all. Such interactions may very rapidly disappear, leaving the collection of components as a disordered set of autonomous things, or the interactions may become self-sustaining, in which case they self-organize into self-sustaining patterns of interactions of various complexity, ultimately defining the collection of components as a single interacting whole. Self-organization implies the spontaneous emergence of structure. Structure, in this particular case, implies a specific, self-sustaining pattern of interactions. Self-organization is a genuine form of causality. But in order to understand how self-organization works in development, one needs a clear idea of the developing system's “evolution rules,” i.e. the principles underlying its developmental change. I hope I can say more about that later.

The temporal process of self-organization, based on the intrinsic dynamics of the system in interaction with other systems or contexts, may take a variety of forms. There may be a pattern of intrinsic fluctuations around what is basically a gradual change towards (relative) stability, for instance when a child gradually improves a particular skill. The gradual change may take the form of accelerations or decelerations, and eventually of temporary regressions. But the change may also be nongradual, that is, it may take the form of a discontinuity, a sudden change, as when one particular pattern of problem solving suddenly passes into another pattern, a process that has been studied in the context of bifurcation or catastrophe theory (e.g., van der Maas & Molenaar, 1992). Or a gradual change may lead to a state where the system becomes critically unstable, which means that any external perturbation of any possible magnitude leads to a sudden change, the magnitude of which is basically unpredictable. For instance, at a critical state of the system, a particular experience or challenge that might be totally insignificant in the great majority of cases, could have a cascading pattern of serious consequences leading to very rapid irreversible change (on self-organized criticality as a possible form of developmental change, see van Geert, 2008). The answer to the question of what causes these various patterns, for instance what causes a discontinuous shift to occur, is that these patterns are caused by the intrinsic dynamics of the system, and this intrinsic dynamics consists of the many interactions and couplings between the system's components. You can further specify your answer by specifying certain properties of the intrinsic dynamics, such as whether the coupling is rigid or weak. But if you ask for a cause in terms of a typical singular antecedent event, the answer will be that if any singular antecedent event exists that indeed triggers a rapid change of considerable magnitude (when a system is in a state of self-organized criticality, for instance), that antecedent event itself can be totally trivial.

D.B.: But what sort of conception of causality lies behind all this?

P.G.: As to the conception of causality implied by complex dynamic systems theory, I think that we should replace the term of causality by an even more basic term, which is that of *interaction* or *coupling* (for a discussion of the interactive view, see Bickhard, this volume). We have seen that in a complex system, many components or subsystems are coupled with or interacting with (some to many) other ones. It is this process of interaction that leads to self-organization, which as we have seen, is a particular form of causality, it is a causal process.

Emergence and Causality

But thanks to the interactions between the components of a complex system, yet another typical feature of complex dynamic systems arises that we need in order to understand causality, which is *emergence*. Emergence means that as a consequence of the interactions between components, the interacting whole acquires or creates new properties, i.e. properties that cannot be reduced to properties of the components or to simple additions of those components' properties. This creation of new properties that transcend the properties of the interacting components is a genuine form of causality (there is an immense literature on emergent properties in physics, for instance, showing that it is a very fundamental property of matter; for developmental psychology, a particularly relevant article is Witherington, 2011; for a good general introduction, see

Clayton & Davies, 2006). It implies a form of bottom-up causality, for instance when the ongoing coordinations between perceptions, actions, memories in an environment with particular properties self-organize into emergent patterns such as skills or abilities. It is important to note that an emergent property does not exist separately from the interactions upon which it comes about. Abstract or operational thinking, for instance, is for all we know an emergent property of particular coordinations and organizations of embodied and contextually embedded sensorimotor processes. No abstract thinking exists that can take place in a form that is totally devoid of sensorimotor processes. The latter are present in overt form as when vicarious objects such as spoken or written symbols are used, or partly “covert” in the form of internal imagery in combination with inner speech. That is, abstract thinking is an emergent enacted property of specific coordinations and couplings between embodied, intentional activities (for a discussion of the enactment position, see Di Paolo in this issue).

Properties such as skills or abilities, like abstract or operational thinking, typically emerge on the timescale of development, in the sense that it takes a lot of practice, learning, self-organizing practices and so forth before they actually get established as more or less stable dispositions of a particular individual. But this does not mean that they are internally represented in the form of frozen, separate causal structures that are taken out of their boxes when needed. It is a consequence of being a complex system that what happens during this long-term process of emergence takes the form of changes on all the levels of the bodily and contextual organization from which a particular process, such as the performance of a skill, actually emerges. These long-term changes are such that the concrete performance of a particular skill *emerges* on the timescale of a real-time activity, by a process that has been called soft assembly (Thelen & Smith, 1994) (although I am not all too happy with the somewhat mechanistic connotation of the word “assembly”).

A very important causal property of emergent organization is that causality is not only running bottom-up, but is also going top-down, that is, emergent properties exert downward causation (for an excellent discussion, see Witherington, 2011, and the commentaries by Ellis & Bloch, 2011, and Lewis, 2011). Emergent properties are affecting, constraining or “affording” the interactions between the components on the basis of which they have emerged (Ellis, 2012). A particular skill, such as reading or making clay pots on a potter’s wheel, is an example of an emergent pattern, that is, a pattern emerging from interactions between all sorts of embodied and embedded perceptual, motor and memory processes in specific material and social contexts that provide the affordances for such processes and are continuously transformed by those processes. The same reasoning applies to any long-term higher-order form of psychological process organization, such as self-esteem, intelligence, personality and so forth (but all these concepts must be given a strictly processual interpretation to make sense in a dynamic systems framework; for an example focusing on self-esteem, see de Ruiter, Van Geert & Kunnen, 2017; on intelligence, see Richardson, 2017).

In summary, I believe that in complex systems such as a developing human person, the fundamental notion of causality should be that of interaction, that is of processes of reciprocal coupling or coordination between a great many components or subsystems. And this interaction comes with “collateral” causal properties such as self-organization, emergence and upward and downward causation. The standard manipulability or intervention format of causality is in fact only one very specific example of the principle of interaction.

The question is of course why the standard praxis of psychological and developmental research factually treats the two-event, antecedent-consequent scheme as the only game in town. The answer, I think, lies in our dominant perspective on nature, which is highly pragmatic. We are primarily focusing on what we can do to change the world such that it complies a little better with our desires and intentions. We are driven by the belief that for every desirable consequent, there must be an antecedent in the form of something that we can manipulate. And we tend to forget that every manipulation is in itself a prolonged process, the course of which greatly depends on how it interacts with and is determined by the prolonged process the course of which it wishes to change.

Causality and Understanding the Process of Development

D.B.: Can you say something about the implications of this conceptualization of causality for our understanding of process in development?

P.G.: I can try to explain this by means of the example of educational or clinical interventions. The standard praxis goes more or less like this. We start with an idea of a given stasis, for instance teachers' habitual teaching practices, and this normal course of events is evaluated against our standards as being suboptimal (e.g., the students' scores on scientific reasoning tests are below a norm). This is the pre-intervention state of events, which is conceived of as a static property of a certain category of persons, teachers for instance. Our aim is to know whether a particular thing or entity, namely the intervention, in general works for a particular category or kind of persons, such as the category "teachers" or the category "5-year-olds with ADHD." All these distinctions are based on a primarily entity- or substance-oriented ontology. We then enter into the intervention stage, that is we "do the intervention," which we tend to see as a well-delineated antecedent event (a precedent to the effect we wish to accomplish). What *really* happens of course is that each trainer enters into a long-term pattern of interactions with individual teachers, taking the form of idiosyncratic processes that unfold as a result of a whole range of idiosyncratic (case-specific) reciprocal couplings between perceptions and actions, couplings between trainer and trainee, between social activities and material objects and contexts, between trainer-trainee interactions and interactions with colleagues, students, and so forth. But in the standard praxis, each of these individual processes is treated as an error-laden expression of an underlying entity, which is the intervention. In addition, we use particular statistical tools to treat the idiosyncratic individual courses of events as the error-laden expressions of an underlying common effect. This effect is viewed as the *result of the causal power intrinsic to this general entity*, which is the intervention. All this directly follows from the standard praxis of defining *the effect of the intervention* as the average (\pm a standard deviation) of the individual effects observed in the form of some effect measurement. That is to say, the "real" things are, first, the intervention as a general object or entity, and the second the effect as a general causal property of that intervention entity. However, what in my view counts as the real thing, namely the processes of long-term individual interactions in each specific teacher or case, is treated as the shadows on the wall, that is, the observable but partly illusory reflections of an underlying, latent reality that must be extracted by averaging or aggregating over these intrinsically misleading, arbitrarily varying individual cases.

Instead of reducing an educational or clinical intervention to a pretest-treatment-posttest scheme over error-laden ensembles of individual cases, we should realize that such interventions are prolonged processes that must be studied on the level of individual cases, which is the only way of getting into the nature, particularities, and finally also generalities of the dynamics (Byrne, 2009; Harvey, 2009). The processes that such interventions consist of take place on various timescales, and two are of primary importance. The first is the timescale of the real-time interactions between, for instance, a teacher and a coach, or a teacher and children in the class, or between parents and children or between a child and a particular object such as a toy. The second is the long-term timescale of change, including variability and fluctuations in the activities and properties of interest, not only during the intervention itself but also a long time after the intervention has taken place. After collecting a sufficient number of such idiosyncratic cases, they can be compared, for instance in terms of the nature of the trajectories and whether or not these trajectories followed the intended course. For instance, in our study on the dynamics of feeding during the introduction to solid food, which implies a typical developmental parental “intervention,” we found four different clusters of change patterns (van Dijk, Hunnius & van Geert, 2012). By making these comparisons against the backdrop of the general explanatory theory of complex dynamic systems, we might hope to arrive at a better understanding of the different ways particular types of interactions lead to intended and unintended effects.

What Kinds of Change Constitute Developmental Change?

D.B.: With respect to your dynamics orientation, what does it mean for a phenomenon to develop? What kinds of change over time constitute developmental change? What changes with, or emerges from, development?

P.G.: There are various possibilities, again. The *first possibility* is based on making a distinction between various timescales, for instance the timescale of events in the form of real-time activities, and events on the timescale of the life span, for instance covering years or decades. Development can then be defined as any process where you see differences in aggregate properties on the long-term timescale. For instance, properties aggregated over a whole range of activities in adulthood that are different from properties of a whole range of activities in children are then seen as instances of development. For instance, they might be activities of logical problem solving, or activities triggered by a particular test. This is probably a rather trivial definition of development, but from a dynamic systems point of view it already has some interesting properties. First, the consistent differences in long-term aggregated properties, such as patterns of problem solving, must be the result of events taking place on the short-term timescale of the activities themselves. That is an example of bottom-up causality. But the long-term differences, that is, the properties that emerge on the long-term time span, have a causal, that is constraining and affording, effect on the short-term dynamics of the corresponding activities, e.g. the concrete solving of a problem by a person or group. This is an example of top-down effects or downward causation.

The *second possibility* is to start with the meaning of development implicit in its etymology, namely the notion of unfolding or unwrapping. It is closely related to the notion of potential and the distinction between potential and actual properties (yet

another Aristotelian contribution to the way we see the world). In this case, one has some sort of implicit idea of what it is that unfolds, or that is being unwrapped, or one has an implicit idea of the nature of the potential. Implicitly, the chosen timescale is that of long-term, life span change. This view amounts to a more or less retrospective perspective on development (looking back, given a particular outcome), and it is a perspective that we see in various classical accounts of development, such as Piaget's for instance (Van Geert, 1986a & b, 1987). The properties of the starting point of development, e.g. in the baby, are defined in function of, or contrastive with, the properties of what is conceived of as the end point, e.g. abstract or operational thinking in adulthood. This provides a particular framework under which the dynamics of development can be understood. It is a form of teleological understanding (the fourth of Aristotle's categories of explanation).

The *third possibility* is to equate the meaning of development to the processes of self-organization and emergence that take place in individual organisms on the timescales that are relevant for their existence. In human beings, those timescales range from very fast bodily, neural and physiological processes, via the timescale of human activities to the timescale of life span change and finally to the timescale of historical changes (as far as such historical changes are manifestly interacting with processes taking place within the confinement of the human life span). The latter is certainly the case if technological and cultural *changes* affect human activities and human life span changes, for instance in modern industrial cultures, where major technological and cultural changes take place over time courses that are of the same scale as the time course of developmental changes in individual persons. If development is likened to emergence, the concept would then by definition apply to all timescales at which emergence occurs. That is, there will be microdevelopment if a process of emergence takes place on the timescale of minutes or hours for instance, as well as macrodevelopment on the timescale of human life spans and intergenerational processes.

An important advantage of this emergence-based conceptualization of development is that it incorporates *novelty* and *creativity* into the framework of development. This is important for our understanding of what I might call *reproductive novelty* on the one hand, and *creative novelty* on the other (I admit that these distinctions are quite fuzzy). An example of reproductive novelty is language development in children: the language they "acquire" is in all likelihood something that emerges out of a myriad of interactions on the sensory, motor, memory, object and context levels, including the level of their own language use in the context of the language use of more advanced and mature speakers (other children, parents, etc.; MacWhinney & Grady, 2015). But the language that emerges is very (but not entirely) similar to the language that has emerged in other children, or in their parents for instance, which is of course vital for linguistic communication to be possible. This process of reproductive emergence is often studied from non-emergent perspectives, postulating processes of transmission or innate structures. Creative novelty applies to all idiosyncratic, individual processes of emergence, leading to new and unexpected patterns of skills or abilities. An idiosyncratic pattern of interaction of a particular autistic child for instance could be an example of that type of emergence, although it would probably not count as creative in the more classical sense of the word, as it does not represent an innovation useful for others (e.g., Kupers, Lehmann-Wermser, McPherson, & van Geert, 2019). In addition to that, we see patterns of creative nov-

elty that often arise as a consequence of interaction between many individuals, in the form of technological or scientific advances, or new cultural and social patterns, or works of art.

Timescales and Developmental Dynamics

D.B.: Do you consider it necessary to distinguish between dynamics at the level of real-time change (the generation of specific organismic actions in adaptation to real-time contexts) and dynamics at higher “emergent” levels of organization (the emergence of new organismic skills and organizations of ability during an organism’s life span)? Or are developmental dynamics nothing more than real-time dynamics added up over time?

P.G.: My tentative answer is: yes, it is probably necessary to make that distinction. The nature of long-term developmental dynamics, and the underlying “rules” of change are different from the nature of the short-term dynamics of organismic activity. Let us take language as an example. A particular speech act of a child, for instance while talking to herself during play, or engaging in some discussion with the parent, is driven by a dynamics of very short-term perception-action loops, memory, intentions, desires or goals embedded and interacting with concrete material and social contexts. We see such utterances unfold over short-term time scales, in the context of specific material and social activities. Meanwhile, there is a long-term process of linguistic change: the structure of the child’s utterances is definitely changing and evolving. These changes can be described by some explicitly formulated grammar that the researcher uses as a formal interpretive framework, provided by linguistics. One can say that under a linguistic interpretive framework, the long-term process amounts to the emergence of grammar, of mature linguistic competence, in the child. The difficult question is of course what this “grammar” means in terms of an underlying causal organization in the child. Anyway, it is highly unlikely that the dynamics underlying this long-term change, this process of emergence, are like very slowed-down versions of the dynamics typical of the short-term speech acts, governed by perception, action, goals and concrete contexts. Maybe such long-term processes invoke neural organizations and reorganizations the dynamics of which are of an entirely different kind than the dynamics of organismic action. But although the nature of the dynamics might be very different, neither dynamic pattern can exist without its direct coupling to the other.

On the other hand, there is something like *scale invariance*, which means that properties looked at from the perspective of short durations are similar to properties looked at from long durations (for examples from cognitive performance, see Kello et al., 2010; Dixon et al., 2012; from self-esteem, de Ruiter, den Hartigh, Cox, van Geert, & Kunnen, 2015). To the extent that scale invariance applies to developmental processes – for instance when microdynamic processes reflect macrodynamic ones – there is no apparent distinction between short- and long-term dynamics, but it nevertheless remains possible that the scale invariant properties are caused by different underlying dynamics.

The problem with all this is that, at present, we know very little about how emergent properties, such as organization of activity in terms of particular skills or abilities, are related to their physical and biological conditions of origination.

So far, psychology, and by implication developmental psychology, has primarily chosen for a substance-oriented approach, which favors a certain parallelism. That is, it is more or less automatically assumed that for every emergent structural property, there is a corresponding specific brain structure that causes it (or represents or encodes it, to use different terminology). In the context of this approach, such parallelism appears totally self-evident, but the assumption is in fact highly dubitable. For instance, water – which is basically an awful lot of water molecules interacting – has various properties: cohesion, adhesion, high solvent power, high-temperature constancy, less density in solid than in liquid form, phases and phase transitions, high boiling point and neutral pH. All these different properties emerge out of the interactions between water molecules caused by one underlying structural property, namely the molecule's hydrogen bonding property (the negative side of one molecule is attracted to the positive side of those around it; <https://sciencing.com/how-is-a-water-molecule-like-a-magnet-13712174.html>).

My general point is that one cannot rely on a substance-oriented principle of property-structure parallelism to prove the difference between short- and long-term dynamics (e.g., real-time activity versus development). But if you look at the nature of the processes taking place on these different timescales, I believe there is reason to (cautiously) assume that the dynamics are indeed different, and that each one creates the conditions for the other (see for instance Steenbeek & van Geert, 2008).

Process and Structure

D.B.: I see that this discussion brings us to the issue of structure, and how the notion of structure relates to dynamics and processes. Does your dynamics orientation relate to an understanding of development framed in terms of psychological structures?

A Dynamic Definition of Structure

P.G.: My career as a researcher in developmental psychology started with language development, and I wrote my dissertation on the language development of my own son in the early 1970s, when the field was dominated by Chomskyan views on linguistic structures, generative grammars, language acquisition devices and so on. I tried to describe his language use in the context of perception and cognition. But I never doubted that the language spoken by my son, over the course of the many activities in which language utterances were a fundamental constituent, was a highly specific and complex structure, rapidly changing at the beginning and gradually zooming in on the linguistic structure typical of mature speakers (mind you that we were speaking a rather particular Flemish dialect at home, and later he would rapidly switch between various other dialects with different phonetic and syntactic properties). As I said earlier, this structure could be described by means of the formal toolbox of grammatical rules, syntactic components and so forth. In a different context, I had learned about Piaget's analyses of children's developing thinking in terms of mathematical structures, such as groups or groupings, or operations. Irrespective of whether this analysis was correct, the message it conveyed to me was this: look, here is this whole range of spontaneous activities of children, of their answers to sometimes deliberately

weird questions of adults. But for the careful observer, these activities have organizational properties that can be *described* by means of the very abstract machinery of (then) modern mathematics and logic. You could say that the variety of real processes of language use or cognitive judgment in children *converged* onto formal structures as described in linguistics or mathematics. But the common interpretation of what Piaget was trying to do here was – and still is – unfortunately very different. It was and is based on what I might call the *substantialization error* (which in a substance ontology is not an error but simply the right thing to do). It means that for every property you can ascribe to an activity, there must be some identifiable entity (substance), in the form of a timeless structure, in the brain or the mind of the agent who can perform the activity to which that particular property can be ascribed (“timeless” means that the time dimension is not needed to describe the structure’s properties, except to indicate its duration of existence; a timeless property is also called “enduring,” which means that it is the same at every moment of its existence; to describe processes, on the other hand, the time dimension is necessary). Hence, if the variety of thought processes in children can be described in terms of properties of mathematical group theory, so the reasoning goes, there must be some sort of timeless structure in the brains of those children that is isomorphic to mathematical group theory, an internal representation of group theory. But how on earth is it possible that young children use a mathematical theory that is understood only by specialist mathematicians? But if the assigned internal structure is simple enough to be intuitively acceptable, substantialization provides the standard explanation of structured performance: an internal representation of grammar generates grammatical sentences, an internal representation of the object concept generates smart object retrieval activities and so forth. This *substantialization error* was rightly criticized by dynamic systems theorists such as Thelen and others (see the classical dynamic systems study on the A-not-B-error by Smith, Thelen, Titzer, & McLin, 1999). But it seems that, for fear that they might be accused of committing this error, for instance in the form of representationalism, dynamic systems theorists tended to deny – or maybe it is better to say tended to avoid emphasizing – that complex structure is indeed an emergent property of the embodied and embedded activities performed by children, and adults for that matter (see also Witherington & Heying, 2015). But in terms of understanding how such structural properties emerge out of the total organismic organization of an embodied and embedded agent, we are currently only scratching at the surface. Such understanding is likely to advance only if we consider the dynamics of the organism-environment system and move away from our focus on the brain as a collection of mechanistic structures from which all these complex structural properties are directly emanating (for a general discussion see for instance Turvey & Carello, 2012, on “intelligence from first principles”).

Stages, Irreversibility and Directionality

D.B.: But how does all that relate to the issue of typical properties of development, particularly as conceived of in the classical theories, namely stages, irreversibility and directionality?

P.G.: These concepts refer to very natural properties of complex dynamic systems. Process properties such as self-organization and emergence lead to stability or metastability. Stability means that typical process properties are actively reproduced

over time, and that systems are spontaneously drawn towards states that can self-reproduce (for a while at least). This relates to the emergence of attractor states, i.e. states that are self-sustaining. The concept of developmental stage is like an application of this general concept of attractor. Complex systems can also self-organize into states of metastability, or into states of criticality. Metastability means that they tend to switch from one attractor to another. The switching of actual performance between various developmental levels over the short-term course of a problem-solving session (e.g., Granott, Fischer, & Parziale, 2002) is an example of metastability (Kelso & Engström, 2006; Kelso, Dumas, & Tognoli, 2013). Criticality means that the system moves towards a state where any minor perturbation can cause an avalanche of changes from very minor to very substantial change over very short periods of time. Such accelerations or discontinuities in the activity patterns of children may give rise to the belief that a new stage has emerged, although the change itself might be confined to a very specific developmental domain (see for instance van Dijk & van Geert, 2007, on discontinuities in language development).

As to irreversibility and directionality, I think we must refer to the fact that complex systems are systems that are very far from thermodynamic equilibrium (this was the approach initiated by Prigogine, e.g. Prigogine, 1980, Prigogine & Stengers, 1984). They are systems with a high level of self-sustaining organization, such as human organisms, or termite colonies, or ecological systems. Self-sustaining organizations survive because they consume a lot of energy, they dissipate energy, in the jargon. It can be shown that, the more such dissipation takes place, the more the processes of organization – such as the emergence of stages or attractors – become irreversible. The reason is that the number of possible paths back to the initial state grows exponentially as the organization into (temporarily) stable patterns consumes more energy, that is, consumes more information. The probability of getting onto the reversed path is astronomically low, which explains the basic irreversibility of the process. And directionality is what you get in self-organizing processes: they follow a path towards attractor states, or to metastability or criticality, as we discussed earlier, and this looks like an inherent sort of directionality or teleology. However, this final destination or telos is the emerging result of the underlying complex dynamics.

D.B.: To what extent is your dynamics orientation compatible with classic organicist/systems approaches to development (e.g., Piaget, Werner, von Bertalanffy)?

P.G.: I see these approaches as entirely compatible with – or assimilable by – the modern view on the nature of complex dynamic systems. For instance, classic developmental theories such as Piaget's or Vygotsky's, are inherently dynamic in their first principles and have very important things to say about the "evolution rules" of developing dynamic systems. Recall that these evolution rules are the basic principles of change, and they provide the causal-process explanation for why a system actually moves through its state space. I think that these classical theories outperform many modern ones in terms of their focus on "first principles of development." In earlier work, for instance I have tried to show that basic principles of change, such as Piaget's assimilation-accommodation principle, or Vygotsky's principle of the zone of proximal development, can be transformed into general developmental evolution (or change) rules. By combining these rules in a formal dynamic framework incorporating a generalized notion of dynamic fields, I have attempted to demonstrate that a wide variety of developmental phenomena – gradual change, discontinuities and temporal stabilities for instance – formally result from the underlying dynamics (van Geert, 1998, 2000).

D.B.: But how does structure relate to dynamics and processes?

P.G.: Under the standard approach, the relationship between structure and process is given by treating structure as an internal causal mechanism (see for instance the causal theory of latent variables, Borsboom, Mellenbergh, & van Heerden, 2004; and Witherington & Heying, 2015, for a critical account). For instance, the structure representing a child's knowledge of math concepts and operations is viewed as a sort of engine taking the math assignment as input and producing math-assignment-making-behaviors and solutions to the math problems as output.

However, under a dynamic systems approach – which is basically processual – structure must be a property of processes, that is, of connected sequences of events, activities and so forth, taking place on a variety of timescales. I think we must look for the structure of a process in its recurrences, that is to say, in the temporal patterning of returning processual components (think for instance about the structure of a musical composition in terms of the pattern of recurrent or returning notes).

But recurrence occurs under a particular structural description by an observer, for instance of what counts as notes in a tune, or of what counts as recurrent components in speech, or in problem-solving activities (recurrence can be studied by means of recurrence quantification analysis, see for instance Guevara, Cox, van Dijk & van Geert, 2017, or by means of state space grids, e.g. van Dijk & van Geert, 2011). For instance, psycholinguists use a structural theory of language (grammar, syntax) to describe a particular vocal stream as a syntactic sequence of prepositions, nouns, verbs, etc. This allows them to follow the temporal recurrence pattern of syntactic structure over the course of verbal parent-child interactions (e.g., van Dijk & van Geert, 2011). These descriptive, instrumental devices – such as the theory of syntax – are themselves the products of historical, scientific development.

D.B.: But if recurrence applies to a particular sort of description of a temporal stream of activities of a person or of interacting persons, what is it then that causes this recurrence to occur? What produces the recurrence?

P.G.: Recall the basic definition of a dynamic system, which is that one state of the system produces another state according to the system-specific evolution rules. We have seen that dynamic systems are based on complex causal networks, the interactions of which converge on a particular sort of dynamics, describable by these evolution rules. I think that structures and structural descriptions – cognitive structures, grammar, concepts – can be used as particular approximations of evolution rules of complex “cognitive” beings such as humans. For instance, given a tool in the form of a structural (i.e., mathematical) description of fractions – the sort of thing schoolchildren seem to like so much – you can generate a generic description or model of a sequence of activities, corresponding with solving such fractions and the sort of errors children can make. This process description is of course only a rough approximation of real processes of solving fractions that you can observe in real children, but it will nevertheless capture a lot of the typical recurrence patterns that you will find in real-time series, over the short- as well as the long-term timescale.

The question is of course how a particular evolution rule relates to an underlying network of causal coordinations or couplings between components on different layers of organization. Take for instance a simple evolution rule such as that describing population growth. It consists of a multiplication of the current population size by a frac-

tion, adding a limiting factor corresponding to limited resources, eventually adding the effect of another population that preys on the first one, resulting in a so-called predator-prey or Lotka-Volterra equation. If we look at the corresponding material-biological organization of predator-prey dynamics, we find a cascade of interacting levels of organization, for instance the biological organization of reproductive physiology in individual animals, the biological organization of feeding and digestion, activities of finding food and sexual partners, of the physiology and physics of food resources, and so forth, almost ad infinitum. This complex material and biological organization, with its myriad of interactions on a variety of levels, *converges* on a dynamics that can be represented by an extremely simple logistic or predator-prey equation, which nevertheless captures fundamental process-causal properties of the dynamics.

D.B.: Is there a privileged level of analysis (i.e., the cellular level, the organismic level, the level of action-in-context, the level of organism-world relations, etc.) for studying the dynamics of psychological functioning and development?

P.G.: The problem is that the notion of privileged level is open to several interpretations. To begin with, there is the epistemological interpretation of the privileged level as the characteristic level of one's scientific discipline. For psychologists, the privileged level comprises psychological phenomena such as human behavior, emotions, consciousness, cognition (and many other things). It is their orientation point, a perspective, from which they can look at other levels, e.g. neurological, sociological or cultural. Looked at in this way, privileged levels are complementary. One level helps understand the other and vice versa.

But the issue is a bit like a Russian Matryoshka doll: what is your privileged level within the level typical of (developmental) psychology? Is it the individual person or is it the person-environment system? Consider the notion of person that appears in either choice: is your privileged level that of the person as a collection of psychological attributes (personality + intelligence + knowledge + ...) or of the person as an adaptive agent? Is your privileged level the level of enduring entities or is it the level of processes? Is your privileged level the level of mind (concepts, knowledge, meaning, etc.) or is it the level of body (biology, neurology, the physics of perception-action couplings, etc.)?

Looked at in this way, the issue of privileged level relates to the notion of explanatory foundations: which level provides the foundation for explaining another level or levels? We have various choices here. One is reductionism, claiming that one level can be explanatorily reduced to, and in the end replaced by, another. The classical example is the reduction of mental properties to underlying biological-neurological-material properties: the reduction of things that a person does to things that the person's brain does (the latter is also known as the mereological fallacy, see Smit & Hacker, 2014). Another, which I prefer, is what I would call explanatory interactionism: explanations of phenomena at different levels interact to generate deeper understanding at each level separately. For instance, processes that you can describe in terms of cognition, concepts and so forth can be better understood by realizing how they are grounded in sensorimotor processes, on the timescale of real action as well as on the timescale of development. Reciprocally, these sensorimotor processes must be understood in terms of the cognitive and conceptual interpretations they enact. Explanatory interactionism is particularly pertinent in cases of emergent properties. What we call concepts or cognitions are emergent properties of particular physically and biologically instantiated processes, invoking interactions between an agent, or interacting agents, a world of material objects in the form of physical and symbolic tools, and

the agents' history or histories laid down in an embodied form (e.g., connection patterns in the brain and body). Understanding emergence in this case requires an interaction between understanding of upward causation (from the physical-biological to the mental, conceptual, etc.) and understanding of downward causation (from the emergent mental level to its physical-biological instantiation).

The position of complex dynamic systems theory in all this is complicated, as usual. Developmental dynamic systems theory as initiated by Esther Thelen, for instance, has rather close family ties with ecological psychology, which takes the physical organism-environment system as its unit of analysis. It is rather reluctant to accept the descriptive level of "mental" emergent properties, such as concepts or representations, as a necessary level of explanation in interaction with the level of physically-biologically instantiated properties, such as perception-action loops. My own position is much more of an interactional flavor, in that I think that concepts and representations and all that stuff must be understood as emergent properties of – and as fundamentally grounded in – these basically physical interactions between organism and environment, and reciprocally, that the latter sort of interaction patterns cannot be understood but in function of the emergent properties that result from them.

Dynamics and Process Ontology

D.B.: Does a focus on the dynamics of development invoke a process ontology (in which time and variability are taken seriously) rather than a substance ontology (in which time and variability are explained away)?

P.G.: An ontology is a general and pervasive set of beliefs on the fundamental nature of being. It is intuitive and *enacted*, rather than explicit and discursive. For instance, the praxis of scientific research in developmental psychology can be said to enact a particular ontology, even if the ontology itself is not a regular (or even accepted) topic of discourse. The standard praxis of developmental psychology enacts a substance rather than a process ontology (Overton and colleagues, who have extensively written on this distinction speak about the Cartesian-split-mechanistic ontology versus the process-relational ontology; e.g. Overton, 2015; Witherington, Overton, Lickliter, Marshall & Narvaez, 2018). Let me try to clarify the difference by means of two explanatory concepts: *photosynthesis* versus *object concept*. With regard to photosynthesis, we would spontaneously opt for a process view, as we understand that photosynthesis is an ongoing process, a series of transformations taking place in plant cells. As photosynthesis is a process, time is an essential dimension of any form of conceptualizing or describing it. But with regard to the object concept, we are used to treating it as a substance, i.e. we enact a substance ontology¹. That is, we are likely to see the object concept as a timeless internal structure, that is, an internal entity, a

¹ A truly gigantic philosophical literature exists on the meaning of substance. A good short introduction to the meaning of the substance concept is Robinson's article on substance in the *Stanford Encyclopedia of Philosophy* (Robinson, 2018). Robinson has various other publications and books on the notion of substance and can be conceived of as a reliable source in this regard. Robinson also defended the view that there are mental substances, which grants the attribution of substance qualities to mental "things" such as intelligence, personality or self-esteem (see Robinson, 2016, pp. 233–247). Another good and comprehensive but short introduction to the notion of substance is an article by Barry Smith (2000; see also Smith, 1997). An important property of a substance is defined in Smith's 1997 article as "substances are that which can exist on their own, where accidents require a support from substances in order to exist" (p. 108).

thing on its own, that can be described without invoking the time dimension. Of course, the object concept is acquired at a particular moment in time, as it may also disappear at a particular moment in time, for instance as a consequence of some severe neurological disturbance. But for its entire period of existence in an organism, the object concept is conceived of as being the same at any time, a static structure, a timeless entity. Or take a concept like intelligence. It lends itself almost automatically to a substance-ontological interpretation, in terms of a timeless non-processual entity. Timeless entities may of course have properties that may change over time, for instance the property of magnitude or intensiveness, but those properties are secondary to the underlying entity.

But what if we interpreted the nature of *object concept* or *intelligence* in exactly the same way as we interpret the nature of photosynthesis, namely as processes, as sequences of transformations with a certain generic, that is to say recurrent property? Process ontology implies that the fundamental nature of being is inherently processual, that changes and transformations over time are an essential feature and that notions of substances as timeless entities are constructed simplifications of temporary process stabilities.

Dynamic systems theory underscores a process ontology. It conceives of processes as patterns of connected change over time, with properties that can be described in the form of a state space, or a network. But these properties are inherently processual, that is to say, time is a necessary component of their conceptualization. Stability means that a process is reproducing its properties over time, causing them to remain the same, for all intents and purposes. The ubiquity of emergent and self-sustained stability on the level of human experience lures us into an ontology that is primarily substance-oriented, where the timeless thing is the fundamental building block of nature, and its eventual change is an inferred, secondary property.

Hence, stability – of our bodies, our social institutions, our health, our knowledge, our personality – is the result of a continuous amount of hard work, in addition to an awful lot of structure and organization in the processes in which stability occurs. The conceptual problem with process ontology is that it runs counter to our linguistic habits to speak about timeless entities (nouns) to which change can be attached (usually by means of verbs).

D.B.: From the vantage point of your dynamics orientation, what does it mean for the study of dynamics to involve a process rather than a substance ontology? What does it mean to take time and variability seriously?

P.G.: It means that we should make the study of *processes* the primary focus of developmental research. A process is a particular sequence of connected events over time, a sequence of states taking place on a variety of timescales, and they show characteristic temporal patterns such as fluctuations, variability, continuities and discontinuities. They are characterized by temporal intertwining with a context, which means that context is a fundamental process-causal component of those processes, and not some added disturbing factor. Processes have a certain typical duration. Processes take place in real individuals, real dyads, real school classes and so forth. Studying processes means that you must explicitly look at all these phenomena, and processes should be studied where, when and for the duration they actually occur, with the individual person (or any other individual case of interest) as the locus of study. If you study self-esteem in adolescents, for instance, you first

have to ask yourself what self-esteem means in process terms, i.e. by what sort of observable process is self-esteem instantiated. It's likely to be a process of communicating, defending and displaying of expressions of self-value, for instance in the form of verbal statements with all their associated properties, such as expressed emotions (Delignières, Fortes, & Ninot, 2004; Wong, Vallacher, & Nowak, 2016; de Ruiter et al., 2015, 2017). It is the sort of process that is likely to unfold if an adolescent is put in a position where he or she has to defend choices, concerns, interests and so forth, often against the opposition of a parent. The self-esteem process can be studied on the short-term timescale of seconds or shorter durations, capturing verbal as well as emotional aspects of an ongoing adolescent-parent discussion. Next, one could study whether such short-term fluctuations cluster into recurrent patterns over the course of the entire discussion, lasting 10 min for instance. By using techniques such as (cross-)recurrence quantification or fractal analysis, the researcher can try to discover properties of the underlying dynamics, for instance in the form of the embedding state space (the number of dimensions one needs to describe the observed temporal pattern as an attractor, i.e. as a recurrent stable pattern; de Ruiter, van der Steen, den Hartigh, & Van Geert, 2017). Finally, one could repeat such observations a few times over the course of weeks or months, to see whether the short-term pattern and its characteristic clusters change as a consequence of the recurrent discussions.

After having collected a number of such processes at all timescales over which they evolved in a variety of individual cases, the researcher can then try to classify the individual processes, in terms of similarities and differences, with the aim of finding out to what extent the processes are idiosyncratic or not. Highly idiosyncratic processes are probably driven by a different type of dynamics than processes that are highly similar across individual cases.

The ideal developmental processes study would follow individuals intensively over the course of their entire development. With the present current technological and statistical means of collecting and analyzing “big data” (many observations over time), following the entire developmental time span should not be a fundamental problem, although there are of course very serious problems with regard to privacy and the integrity of the person (see for instance <https://blog.stephenwolfram.com/2012/03/the-personal-analytics-of-my-life/>).

The standard research praxis, on the other hand, typically enacts a substance ontology. Self-esteem, for instance, is seen as a sort of timeless psychological entity, with attached properties – such as intensity – that can vary over time. Variability is introduced as a contingent and accidental property, in the form of a distinction between trait and state self-esteem where the expression of the internal stable trait gets confounded by variable and accidental context influences. This internal entity (substance) can be accessed by means of dedicated measurement operations, using measurement tools such as tests. The entity *self-esteem* is extensionally defined by all persons having self-esteem (including some other differential properties of interest such as age or gender). This implies that studying self-esteem and its properties requires a sample of individuals that is statistically representative of the total extensional set (the population of people having self-esteem). This way of stating the nature of psychological entities is associated with other requirements, generalizability in particular, that are highly specific and only meaningful in the context of this particular substance ontology. Generalizability is al-

most invariably equated with the question of whether a sample-based statistic, such as an average, comes sufficiently close to the corresponding (imaginary) population-based statistic. In truth, the standard generalization practices in terms of representative samples of “subjects” are very poor anyhow, as those samples are typically drawn from WEIRD populations (Western, educated, industrialized, rich, democratic; Rad, Martingano & Ginges, 2018; see also <https://www.sapiens.org/culture/weird-cultures-human-nature/>). Unfortunately for process theory, the enactment of a substance ontology in psychological research is a very powerful, self-sustaining attractor state itself.

D.B.: Catchphrases like “embodiment” and “embeddedness” are also routinely associated with a focus on developmental dynamics. How are these terms conceptualized in your dynamics orientation? How are other terms, like “novelty,” “nonlinearity,” “complexity,” “system” and “emergence,” conceptualized in your dynamics orientation?

P.G.: Embodiment and embeddedness are inextricably connected with being an *organism*. The first Dutch translation – in 1890 – of Darwin’s *On the Origin of Species*, provides a now obsolete but highly illuminating Dutch word for *organism*, “*bewerk-tuigde wezens*,” which, literally retranslated, means “beings equipped with tools to work with”². Hence, embodiment primarily means that organisms are being equipped with tools to do things that are in the organism’s interest. One very specific tool is a human hand, with which humans can make artifacts that serve as material extensions of manual acts (basically almost anything that technology has produced). But these artifacts generate entirely new properties, for instance in terms of temporality and functionality. You can hold a certain amount of grain in your hand for a short while, but you can also make a pot to hold a much bigger amount of grain for a long period of time. Another very specific bodily human tool is the speech organ (lips, teeth, alveolar ridge, hard and soft palate, velum, uvula, vocal folds, glottis and various parts of the tongue). You could say that the physical speech organ allows you to produce sound patterns that are extensions of your thoughts and perceptions. But just as with material objects, structured sound patterns create entirely new possibilities for thought in the form of language (which your hands can transform into enduring material symbolic objects in the form of writing for instance). That is, human beings embed themselves in environments that are infinitely complex extensions of the sentient and acting human body, providing an ever-extending range of emergent properties in the form of opportunities that these extensions allow for. That is, development implies the process of being embedded in and growing into an extended body and extended materialized mind with properties that infinitely increase those of the human body as a biophysical object. And this process takes place in the form of a continuous interaction with other human beings, occupying different places in this world of opportunities (e.g., with different levels of maturity, skill, expertise and so forth). This general framework is currently known as the 4E approach to psychological phenomena as being embodied, embedded, extended and enacted (to which we should add the notion of interaction, I think).

Even the simplest possible dynamic process model implies an underlying complex process organization, with characteristic properties. These properties are emergence,

² The translator, Dr. H. Hartogh Heys van Zouteveen, translates “organisms” by *bewerktuigde wezens*: *wezens* = beings; *be-(werk-tuig)-de*: *be-...-de* = equipped with, issued with, *werk-* = work, *-tuig* = equipment, necessities. The term is no longer in use in Dutch and is unfortunately replaced by the semantically opaque “organisme.”

nonlinearity, self-organization, self-organized criticality, scaling (in)variance, timescales and so forth. Emergence is the general form of processes that create novelty, i.e. properties that result from self-organization, that are not reducible to properties of the underlying components, and that create downward causation, as explained earlier (e.g., when we discussed the question of what kinds of change constitute developmental change).

Methodology and Analysis of Dynamics

D.B.: What does your dynamics orientation entail for developmental methodology and analysis, and, more generally, for orthodox scientific approaches to psychological functioning and development like the hypothetico-deductive method? What sorts of methods and analyses are and are not appropriate for the study of dynamics in development? What are appropriate units of analysis for the study of dynamics in development?

P.G.: We have an enormous wealth of intuitive experiences with developmental processes, as we are direct witnesses to such processes ourselves. But we have surprisingly little scientifically validated information about actual, individual developmental processes at the timescales that are relevant for understanding them. As to long-term patterns, what counts as longitudinal research, for instance, is usually little more than very shallow observations (e.g., test scores, aggregated questionnaire data), with long intervals in between, based on the simplest possible growth patterns (linear, asymptotic, etc.). Information about short-term processes in individuals, i.e. on how individual subjects arrive at their answers in some experimental setup, is usually flushed through the drain of statistical aggregation in the form of average differences between groups or experimental conditions. So, given our impressive scientific ignorance with regard to actual developmental processes, we should put much more emphasis on exploratory research, in the form of so-called case studies, which are in fact studies on the level where actual processes take place. Process research is extremely labor intensive, and for many process studies it is an illusion that the typical research resources will cover the costs and efforts of more than just a few cases. But as such detailed process studies become more frequent, we might start looking for similar patterns, typical differences and so forth.

The theory on which all these process studies should be grounded is the very broad (meta-)theory of complex dynamic systems. That is, we should base our research on various, connected general assumptions: that development is a process of self-organization and emergence; that the dynamics are caused by the way the components, properties or “variables” are interacting in the organism-environment system over time; that these interactions produce typically nonlinear patterns of change, and so forth, until proven otherwise. We should start from the assumption that the *intra*-individual variation that constitutes the essence of a process cannot be inferred from the *inter*-individual variation that forms the basis of almost all models in psychology (the so-called non-ergodicity assumption, e.g. Molenaar & Campbell, 2009). This implies that the typical sample-of-individuals-based methods of the standard research praxis are not appropriate for the study of developmental dynamics. The theory of complex dynamic systems provides a general ground for expectations and eventually hypotheses that can guide our research. But these expectations and hypotheses must be based on “first principles,” i.e. basic principles of organization in complex organismic systems. Finding out what the relevant first principles are for development is still a major challenge.

To explore the current terra incognita of developmental processes, we must use all the tools we have. They can take the form of highly sophisticated statistical analyses of time series, such as dynamic factor analysis or analysis of fractal dimensions (e.g., Molenaar, Lerner & Newell, 2013). Another technique is recurrence quantification, using the temporal recurrence of process properties to discover general properties of the underlying dynamic system (e.g., Guevara et al., 2017). And there's the widely used state space grid method (Hollenstein, 2013).

Our analytic tools can take the form of exploratory observational studies of ongoing processes, eventually with interventions or perturbations that allow us to better understand the underlying dynamics. They can use various forms of exploratory machine learning techniques, cluster analysis and the like. They can take the form of qualitative descriptions of observed interactions, or they can be based on time-serial coding of observed events and quantitative time-serial methods. Or they can take the form of dynamic systems or agent-based simulation models (e.g., Schöner & Spencer, 2016, on dynamic field models, or Steenbeek, van der Aalsvoort, & Van Geert, 2016, on agent-based modeling of dyadic play). It goes without saying that even with the most tolerant methodological approach, researchers should be open about their methods, their observations or experiments, so that their studies are reproducible in terms of methods and approaches, and fully open to peer evaluation. The recent, lively debate on replicability of findings in the behavioral sciences is primarily focusing on reproducibility of results and advocates exact reproducibility of methods as a condition for obtaining the first (Zwaan, Etz, Lucas, & Donnellan, 2017). However, in a person- and process-oriented methodology, reproducibility of results is a very tricky issue, as many processes occurring in complex dynamic systems will tend to be highly idiosyncratic and context-specific (for a discussion, see van Geert & de Ruiter, 2019). What counts is whether this idiosyncrasy is understandable in the context of an underlying theory of complexity, and whether the general approach of the study can be used by other researchers.

As to the units of analysis, I take a similar agnostic (promiscuous, tolerant, whatever...) position as with regard to the methods to be applied. The units of analysis will depend on the timescale of interest (real-time activities vs. long-term changes). Any structural, formal description of recurrent patterns in the stream of human activities can serve as the basis for establishing units of analysis. This includes units of analysis based on cognitive, linguistic or other formal structures. But any unit of analysis one chooses is ultimately instantiated in an embodied and embedded processual condition, and this must be taken into account if one wishes to understand the dynamics of the units so described.

D.B.: Do you have a final concluding remark?

P.G.: I think that the field of developmental research itself is an example of a complex dynamic system, and the changes in the prevailing practices of research and theory building will follow one or some of the many types of trajectories complex dynamic systems theory describes. It is possible that we might see a – regrettable – sort of bifurcation in the field, leading to, on the one hand, a typical substance approach, coexisting with, on the other hand, a typical processual approach, with relatively little interaction between the two. But without a serious effort to study processes, we might remain stuck in the self-sustaining dynamics of a research praxis that imposes its inherent substance ontology as the only possibility. To paraphrase Captain James T. Kirk of the *Starship Enterprise*: “Process: the final frontier. ... Our mission: to explore strange new worlds. ... To boldly go where no man (m/f) has gone before!”

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